Astrophysics and Cosmology reviews

and

(possible) Cosmology Data Group

Subir Sarkar

University of Oxford & Niels Bohr Institute

Particle Data Group Advisory Committee Meeting, CERN, 7th October 2012

Reviews (revised late 2011)

- **Big-Bang Cosmology:** Keith Olive (Minnesota) & John Peacock (Edinburgh)
- **Big-Bang Nucleosynthesis:** Brian Fields (Illinois) & Subir Sarkar (Oxford)
- **Cosmological Parameters:** Ofer Lahav (UC London) & Andrew Liddle (Sussex)
- **Dark Matter:** Manuel Drees (Bonn) & Gilles Gerbier (CEA Saclay)
- **Cosmic Microwave Background:** Douglas Scott (UBC) & George Smoot (LBL)
- **Cosmic Rays:** Jim Beatty (Ohio State) & John Matthews (Louisiana State)

  +

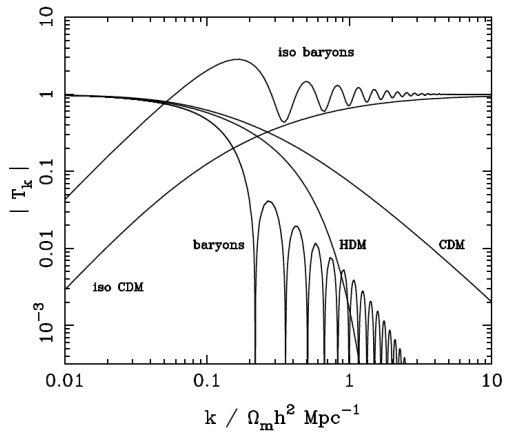
- **Experimental tests of Gravitational theory:** Thibalt Damour (IHES Paris)
- **Neutrino mass, mixing & oscillations:** K Nakamura (IPMU Tokyo) & Serguey Petcov (SISSA, Trieste)

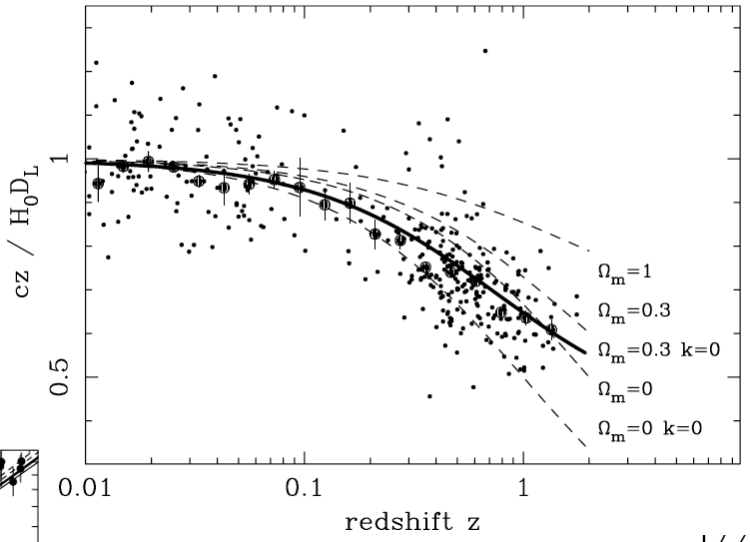
➢ 10 theorists, 5 experimentalists (7 - Europe, 1 - India, 1 - Japan, 6 - N America)

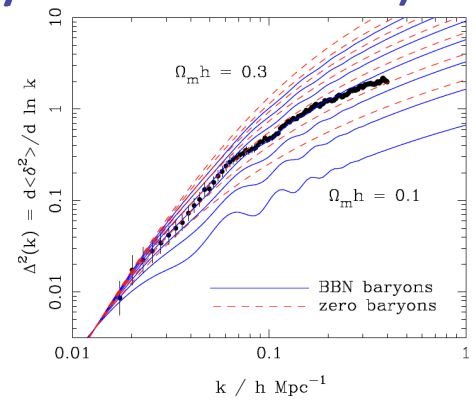
➢ Fast moving fields … all reviews are updated (bi) annually

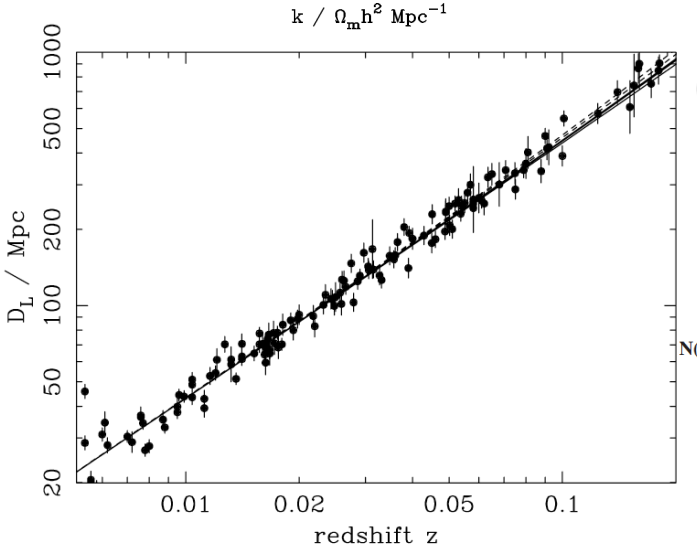
Big Bang Cosmology

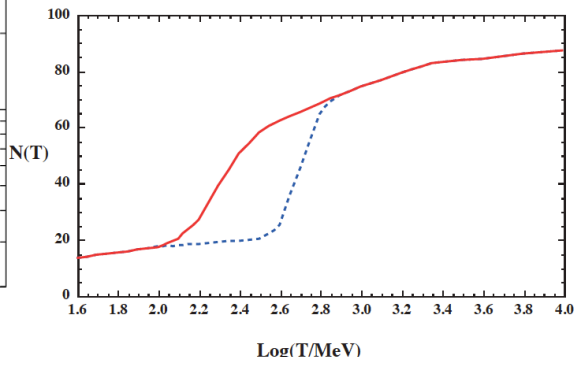
- Succint overview of ‘standard model’
- Introduces concepts, notation, links between other reviews
- Discusses observational basis (for dark energy domination)

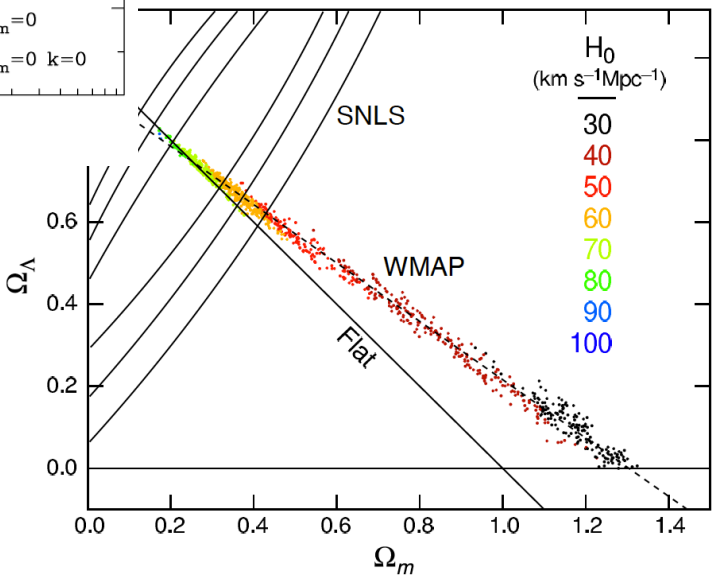










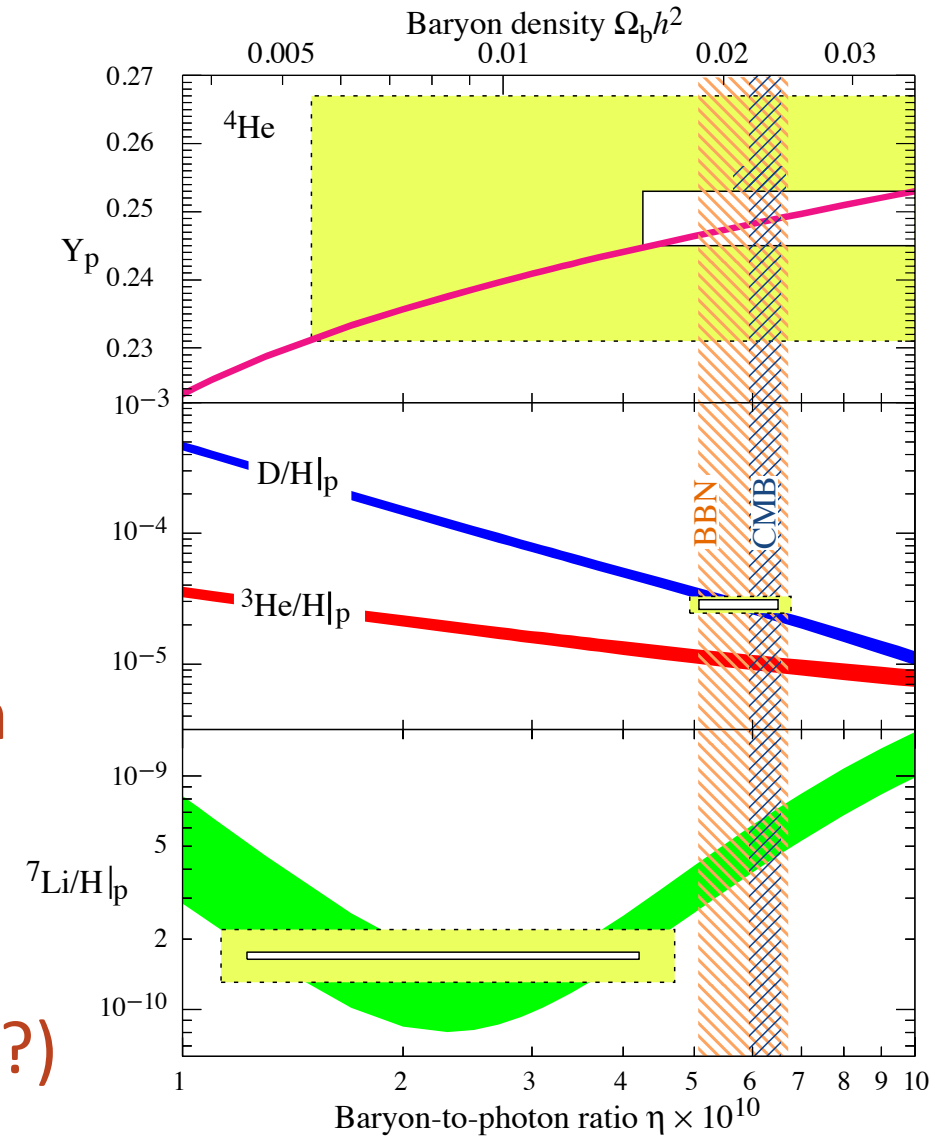


Big Bang Nucleosynthesis

- Summary of ‘deepest direct probe of the early universe’
- Critique of quoted *inferred* primordial abundances
- Emphasises agreement with CMB determination of η
- Constraints on new physics
- ‘Cloud on horizon’ …

the ^{7}Li (and possibly ^{6}Li) problem (new physics or astrophysics?)

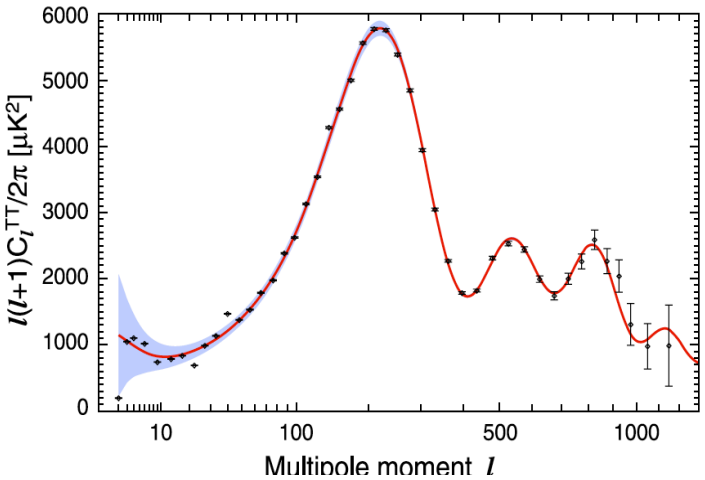
… also weak indication for faster expansion rate (singlet neutrino?)

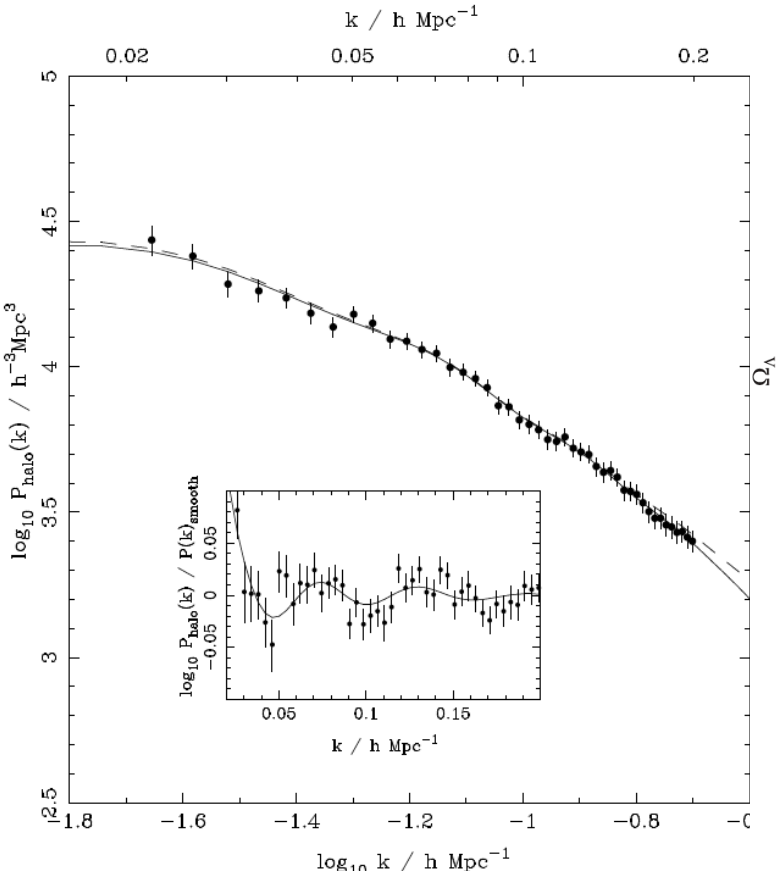


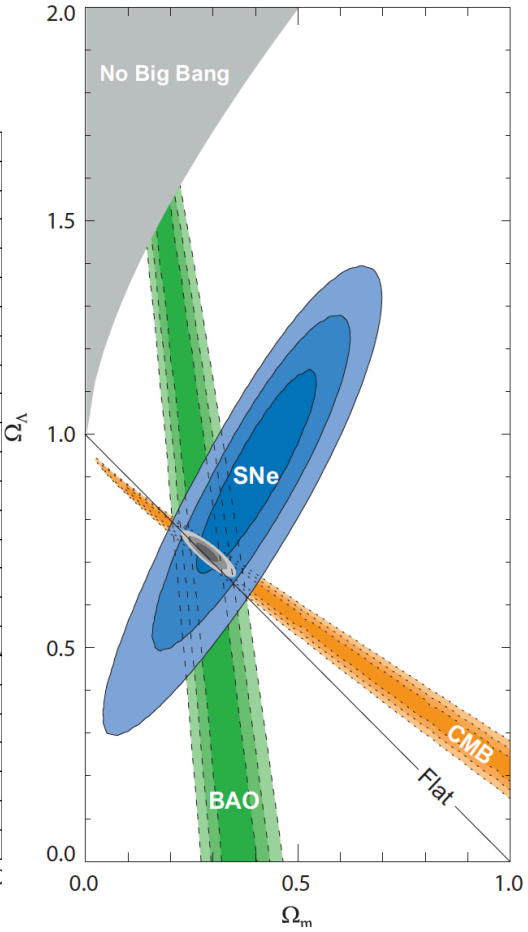
Cosmological Parameters

- Some overlap with BB cosmology and CMB reviews
- Discussion of density perturbation generation from inflation and the growth of large-scale structure
- Wide-ranging survey of different techniques for measuring content of universe

	WMAP7 alone	WMAP7 + BAO $+H_0$
$\Omega_b h^2$	0.0225 ± 0.0006	0.0226 ± 0.0005
$\Omega_{cdm} h^2$	0.112 ± 0.006	0.113 ± 0.004
Ω_Λ	0.73 ± 0.03	0.725 ± 0.016
n	0.967 ± 0.014	0.968 ± 0.012
τ	0.088 ± 0.015	0.088 ± 0.014
$\Delta^2_{\mathcal{R}} \times 10^9$	2.43 ± 0.11	2.43 ± 0.09
h	0.704 ± 0.025	0.702 ± 0.014
σ_8	0.81 ± 0.03	0.816 ± 0.024
$\Omega_m h^2$	0.134 ± 0.006	0.135 ± 0.004

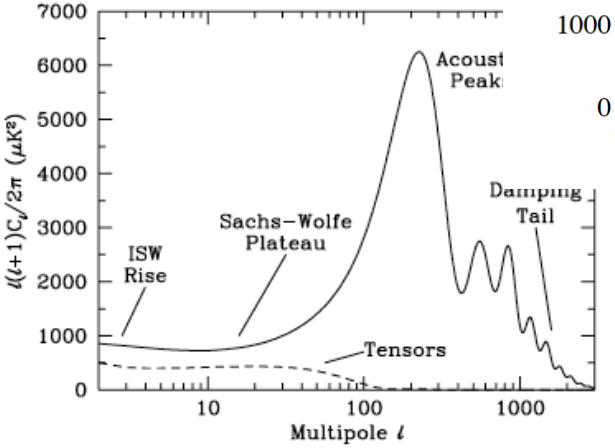


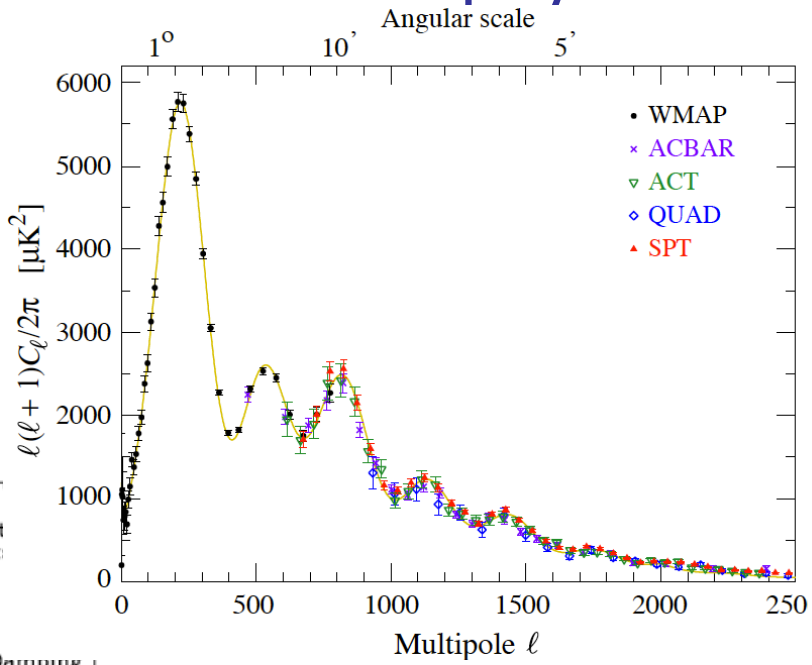


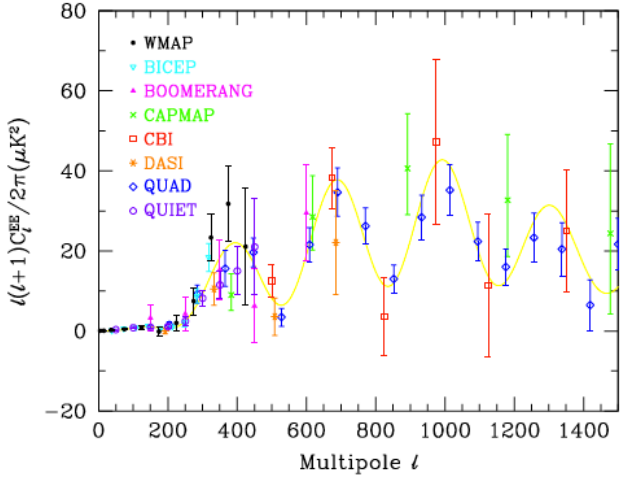


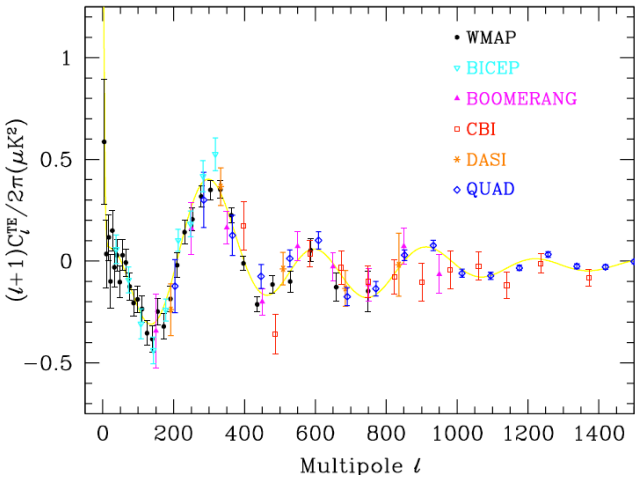
Cosmic Microwave Background

- Discussion of physics of CMB anisotropy generation
- Summary of current observations and implications for cosmological parameters
- Constraints on fundamental physics



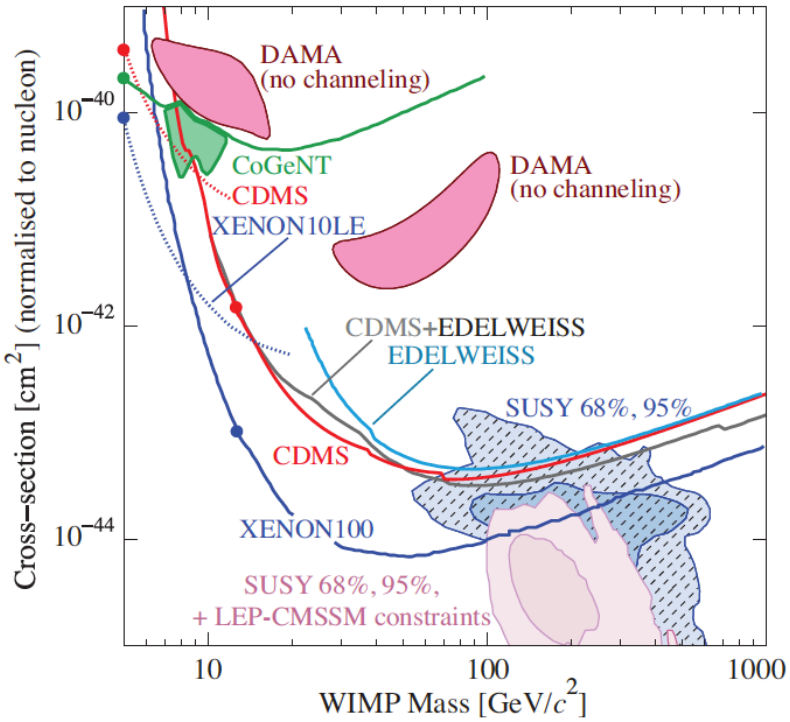


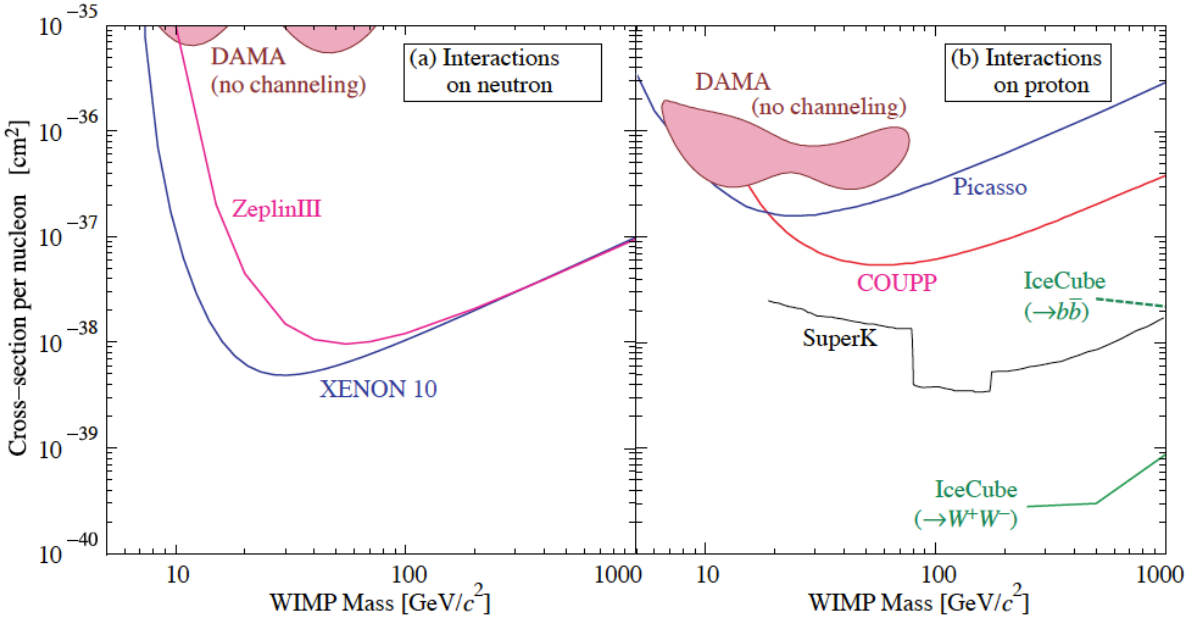




Dark Matter

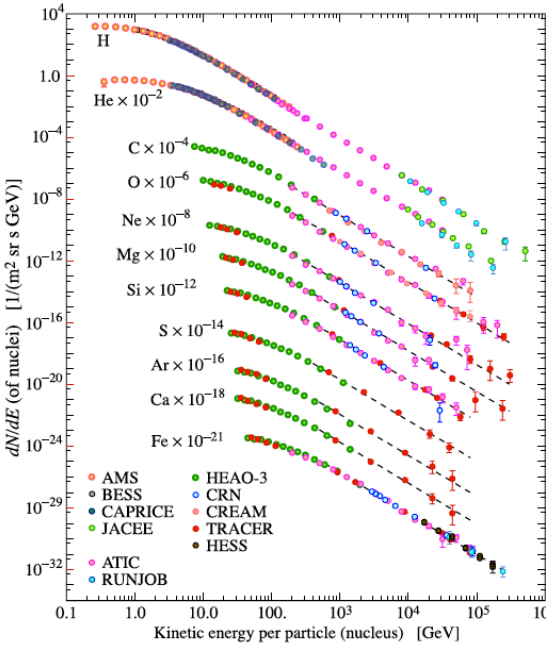
- Summary of astronomical evidence for dark matter
- New particle candidates
- Detailed discussion of experimental approaches to WIMP and axion detection - mainly on direct searches, also some indirect searches

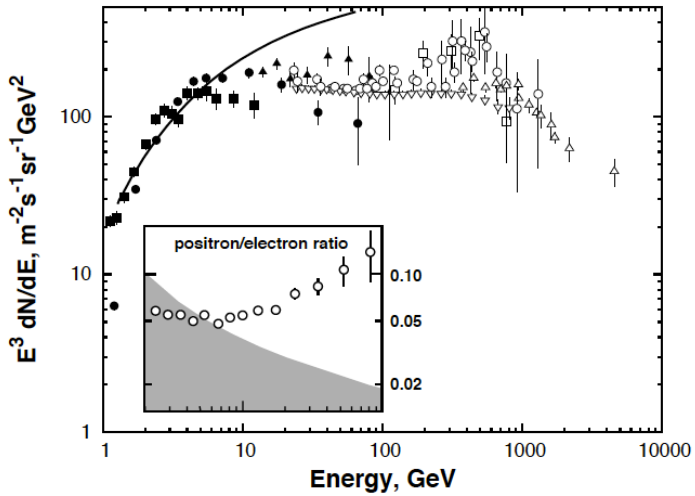


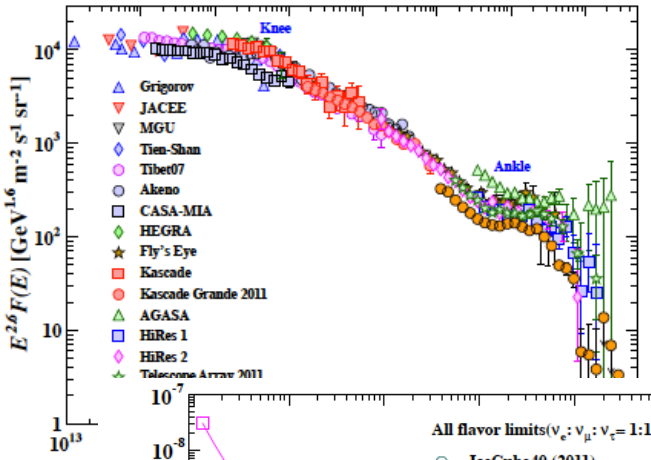


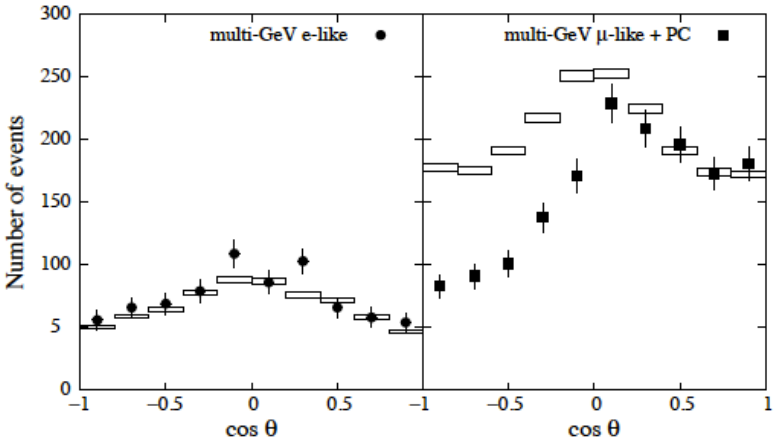
Cosmic Rays

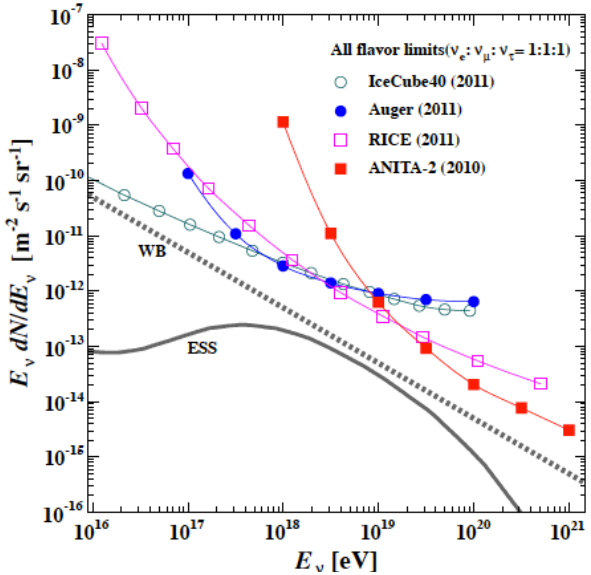
- Summary of phenomenology (100 year old mystery!)
- Wide ranging discussion (atmospheric neutrino oscillations, positron anomaly, ‘GZK suppression’, cosmic neutrinos …)



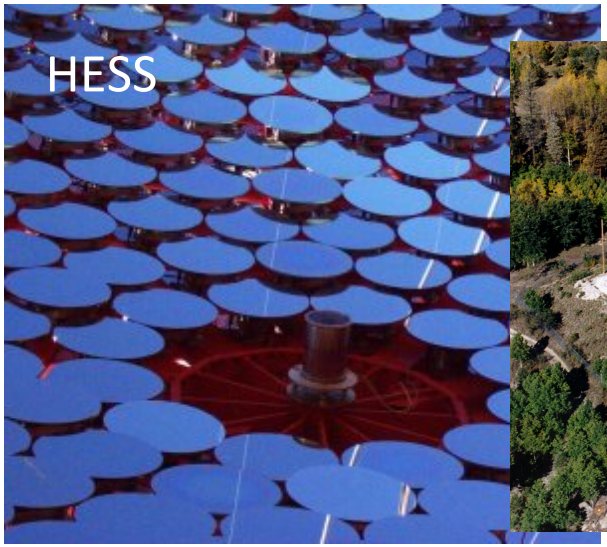


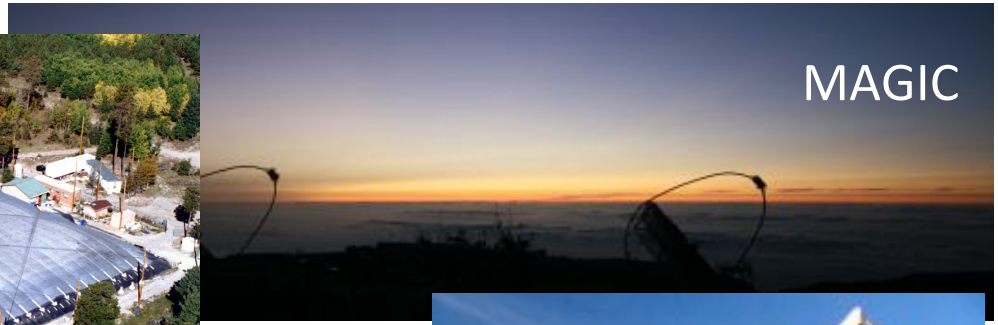


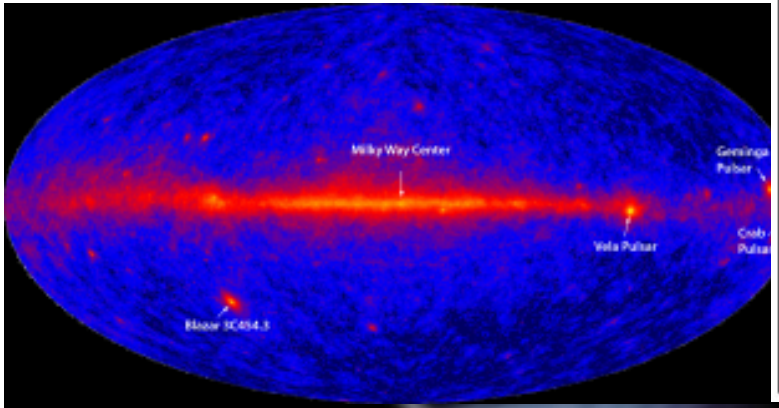


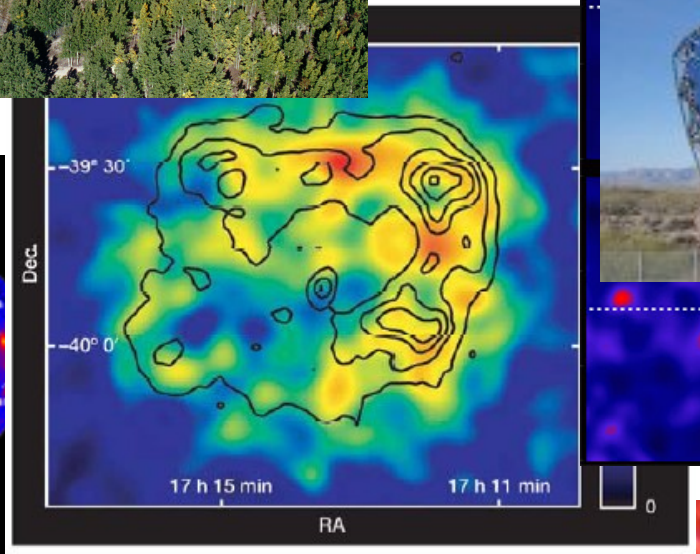


It would be good to have a review of γ-ray astronomy …









Arguably most productive area of astroparticle physics - mainly relevant to high energy astrophysics … but also to fundamental physics (dark matter, tests of LIV, cosmology etc) – two major new projects in the pipeline: HAWC and CTA

Listings (under 'Astrophysics and cosmology')

- **Table of Astrophysical constants and parameters**

("*The values and uncertainties for the cosmological parameters depend on the exact data sets, priors, and basis parameters used in the fit. Many of the derived parameters reported in this table have non-Gaussian likelihoods. Parameters may be highly correlated, so care must be taken in propagating errors …*")

- **Axions and other very light bosons (Searches for)**

Expanded section on neutrinos:

- **Neutrino properties**
- **Number of neutrino types**
- **Neutrino mixing**
- **Heavy neutral leptons (Searches for)**

- **Supersymmetric particle searches**

Increasing number of experiments in particle astrophysics & cosmology

❖ **Dark Matter**

CDMS, COUPP, DAMA/LIBRA, DEAP/CLEAN, DM-Ice, Edelweiss, KIMS, Picasso, SIMPLE, XENON, ZEPLIN, ... → ANAIS, ArDM, DARK SIDE, TEXONO, DARWIN, EURECA, LUX, MAX, PANDA-X, WARP, XMASS, …

❖ **Dark Energy**

DES, PAN-STARRs, LSST, BigBOSS, DeSpec, … → EUCLID, SKA, WFIRST …

❖ **Cosmic Microwave Background**

ACT, BICEP, CBI, DASI, QUAD, SPIDER, SPT, Planck,WMAP, … → BBO, …

❖ **Gamma-ray**

Fermi, HESS, MAGIC, MILAGRO, VERITAS … → CTA, HAWC …

❖ **Cosmic-Rays & Neutrinos**

Auger, CREAM, KASKADE-Grande, PAMELA, TA, … → AMS …

ANITA, Antares, IceCube, RICE … → ARA, ARIANNA, KM3NeT …

Concerns

Astro/cosmo community does *not* take much notice of RPP?

Possible reasons:

1) RPP is published in mainstream *physics* journals
2) Astro community less used to 'standard' numbers?
3) Astro 'culture' is Bayesian rather than frequentist?

Suggested strategies:

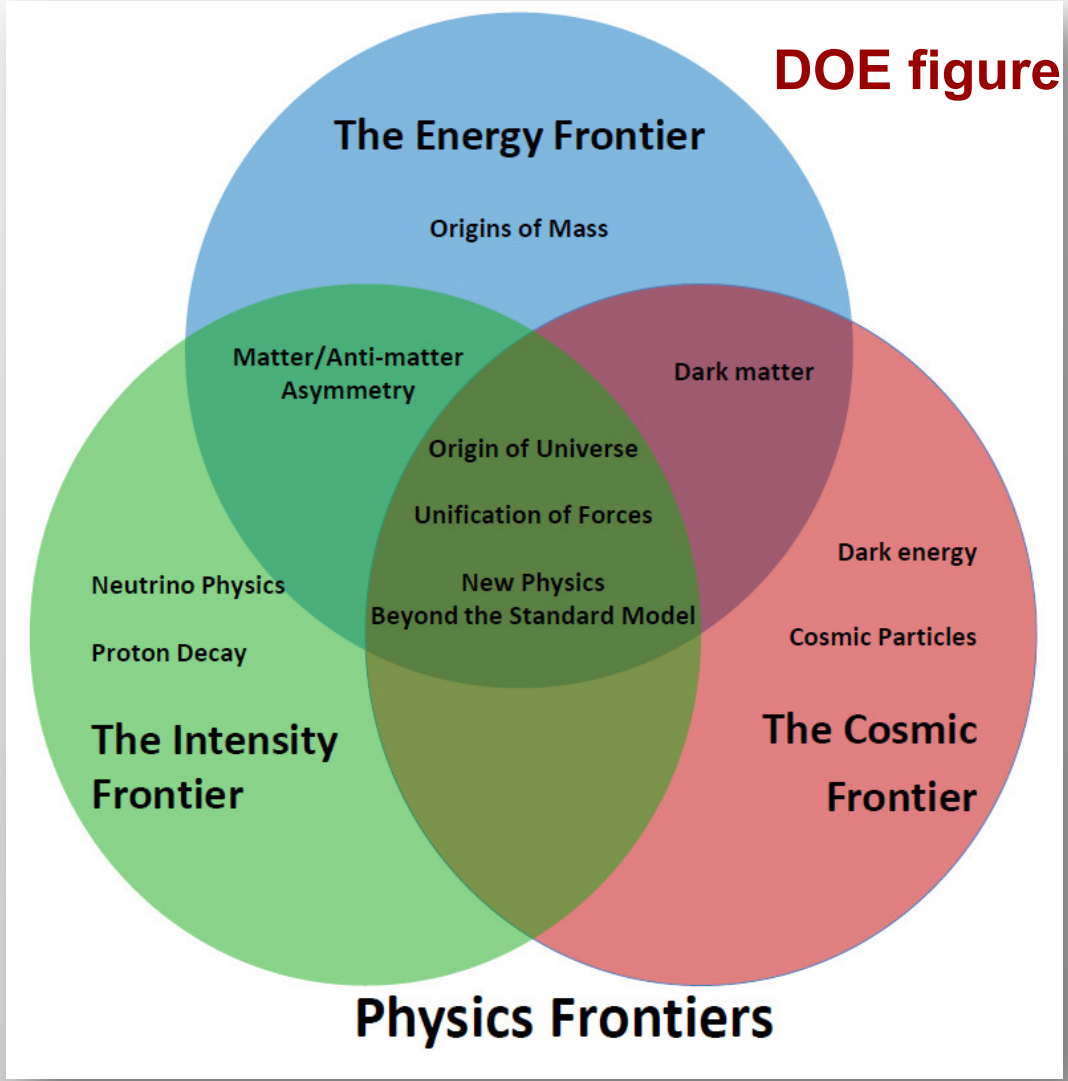
1) Submit all reviews to arXiv [astro-ph] *concurrently* with RPP publication (provide hyperlink to PDG webpage)
2) Organise meetings of common interest (e.g. statistical analysis) to bring communities together
3) Start 'Cosmology Data Group'?

Cosmology Data Group ?

Should we seek funding for a quasi-independent CDG sharing some infrastructure and basic principles but with independent staff?

The Cosmic Frontier

PDG currently covers the energy frontier and the intensity frontier.



Motivation

Cosmological data volume and variety is increasing rapidly, often with direct impact on HEP questions.

The nature of inflation and the quantum vacuum at ~10^{16} GeV, the nature of dark energy and the quantum vacuum at 10^{-3} eV, the mass of neutrinos, new scalar fields, and the fundamentals of gravity and dimensions are informed through cosmological efforts.

Data from BOSS, Dark Energy Survey, Planck and ground-based CMB experiments vastly overwhelms previous maps of the universe.

Need to handle this data, condense it, and interpret it to make contact with the key physics questions of "the nature of matter, energy, space, and time".

Possible CDG Coverage

Three cosmologists' thoughts on possible coverage.

- Eric Linder (LBNL)
- Keith Olive (Minnesota)
- Subir Sarkar (Oxford) -- present at this meeting

Possible CDG Coverage

Eric Linder:

*** Compiling cosmological observation results into an "end-user" table (or matrix of tables) of cosmological Further useful information could be provided in the form of a triangle of plots of the 2D confidence contours for each pair of major parameters.**

*** Review article on cosmological constraints on sum of neutrino masses.**

*** Review article on cosmological distance measurements, including a table of distance measurements to various redshifts, from the combination of Type Ia supernovae and baryon acoustic oscillations.**

*** Review article on cosmological growth measurements, including a table of growth measurements to various redshifts, from redshift space distortion measurements by spectroscopic cosmological surveys.**

*** Expanded coverage of testing non-Gaussianity through both the CMB and large scale structure, and the implications for inflation models.**

Possible CDG Coverage

Keith Olive:

I think data sections for astrophysics and cosmology are good. I always have.

The new sections are new work in that they should go far beyond the limits on particle properties from astrophysics that we now include.

Do we want data sections on determinations of cosmological parameters?
Do we want sections on measurements of the astrophysical quantities that go into the determinations of cosmological parameters.

Overall, I think it can be useful to have data sections on relevant astrophysical measurements. There would have to be considerable brainstorming to decide just what measurements would be included and in what format etc.

Its not as clear as in particle physics as you need to extract a physical quantity of interest.

In any case, my overall sentiment is positive.

Possible CDG Coverage

Subir Sarkar:

Good idea – has been thought of several times earlier but its time has perhaps now come ... however there are both technical and `cultural' aspects that need to be discussed carefully:

- Cosmologists are natural Bayesians (the experiment has been run!) … uncertainties are usually estimated from posterior distributions in MCMC scans of multi-parameter space.

So far the PDG has only quoted results from frequentist analyses. If Bayesian analyses are to be quoted then should insist that all assumed priors are clearly stated along with the conclusions! (E.g. *WMAP assumes* a value for the Hubble parameter H_0 to infer that the space curvature is close to zero (from the 1st CMB acoustic peak position) … and then infers a value for H_0 now *assuming* $k = 0$)

- Cosmologists are mainly concerned with *establishing* their 'standard model' (*cf*. particle physicists who are mainly concerned with wishing to go *beyond their* 'Standard Model')!

There should be a critical discussion of the foundations of the standard cosmological model (in particular the observational evidence for large-scale homogeneity, isotropy of the Hubble expansion, gaussianity of the density field etc), and discussion of anomalies (e.g. unexpected alignment of low CMB multipoles, excessive peculiar velocities, too many colliding clusters …)

Possible CDG Coverage

Subir Sarkar:

In discussions with other experts who are writing the cosmology reviews, concerning the need to present the whole picture rather than just the 'standard viewpoint', it has become clear that there are very different viewpoints concerning the purpose of these reviews, *e.g.* one author wrote:

"I think it's perfectly reasonable for us to have these discussions. But they don't belong in the reviews we are writing for the Particle Data Book, which should represent the consensus view of these parts of astrophysics"

However as I understand it, the policy of the Particle Data Group is to outline *"the critical issues in physics that help to shape our understanding of the Universe"*. Does this not mean that the (largely particle physics) readership should be given a broader picture than just the sanitised version?

Given that there is e.g. no fundamental physical understanding of 'dark energy', or of inflation (cosmological constant problem!), these must be regarded *effective* descriptions which enable contact to be made with a large body of observational data … in that case it is particularly important that the PDG should *not* present as established facts, issues which are still under discussion!

These concerns do *not* arise in 'astroparticle' topics, e.g. cosmic rays, dark matter, γ-ray astronomy, neutrinos, … which are well-founded in today's particle physics

Possible CDG Coverage

Astrophysics > Cosmology and Extragalactic Astrophysics

On the measurement of cosmological parameters

Rupert A. C. Croft, Matthew Dailey (CMU)

(Submitted on 14 Dec 2011)

We have catalogued and analysed cosmological parameter determinations and their error bars published between the years 1990 and 2010. Our study focuses on the number of measurements, their precision and their accuracy. The accuracy of past measurements is gauged by comparison with the WMAP7 results. The 637 measurements in our study are of 12 different parameters and we place the techniques used to carry them out into 12 different categories. We find that the number of published measurements per year in all 12 cases except for the dark energy equation of state parameter w_0 peaked between 1995 and 2004. Of the individual techniques, only BAO measurements were still rising in popularity at the end of the studied time period. The fractional error associated with most measurements has been declining relatively slowly, with several parameters, such as the amplitude of mass fluctutations sigma_{8} and the Hubble constant H_0 remaining close to the 10% precision level for a 10-15 year period. The accuracy of recent parameter measurements is generally what would be expected given the quoted error bars, although before the year 2000, the accuracy was significantly worse, consistent with an average underestimate of the error bars by a factor of ~2. When used as complement to traditional forecasting techniques, our results suggest that future measurements of parameters such as fNL, and w_a will have been informed by the gradual improvment in understanding and treatment of systematic errors and are likely to be accurate. However, care must be taken to avoid the effects of confirmation bias, which may be affecting recent measurements of dark energy parameters. For example, of the 28 measurements of Omega_Lambda in our sample published since 2003, only 2 are more than 1 sigma from the WMAP results. Wider use of blind analyses in cosmology could help to avoid this.

Cannot just take average of measurements!

Comments: 16 pages, 16 Figures, submitted to MNRAS
Subjects: **Cosmology and Extragalactic Astrophysics (astro-ph.CO)**; General Relativity and Quantum Cosmology (gr-qc)
Cite as: arXiv:1112.3108 [astro-ph.CO]

Possible CDG Coverage

No decision now.

Just a subject for discussion.